THE MACHINE INSIDE

"VOYAGES OF DISCOVERY"

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Applied Mathematics Computer Science Neuroscience

Why study the brain?

BRAINS IN ACTION

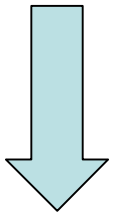
FACE RECOGNITION

M2VTS Multimodal Face Database

TRANSLATION

French:

Les places américaines sont également attendues en baisse.



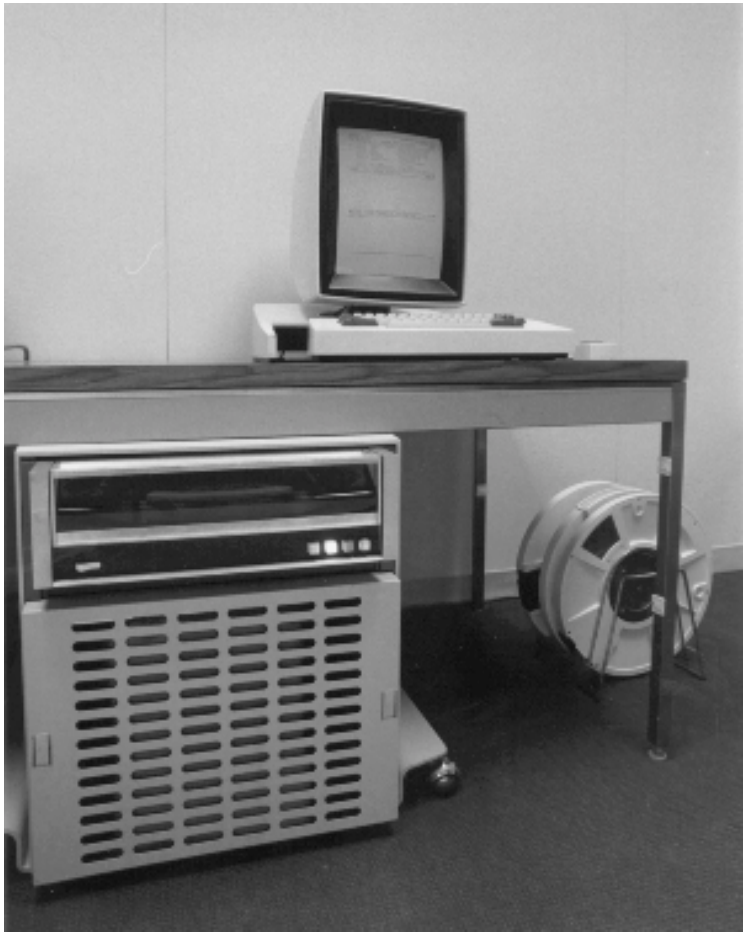
*"The translation you are seeing was produced automatically by **state-of-the-art technology** without the intervention of human translators"*

English:

The American places are also awaited in fall.

Google

XEROX ALTO 1973

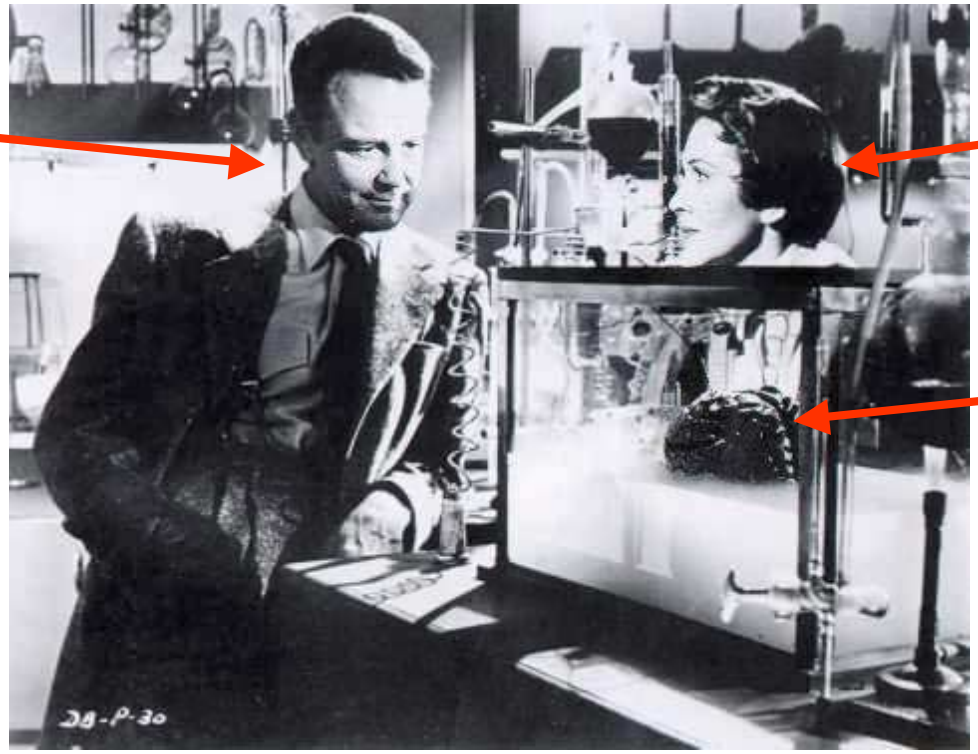


Dell workstation, 2001

BRAIN-LIKE COMPUTERS

Image: Jonathan Oliver

BRAIN-COMPUTER INTERFACES



"If I could find … a code which translates the relation between the reading of the encephalograph and the mental image …the brain could communicate with me."

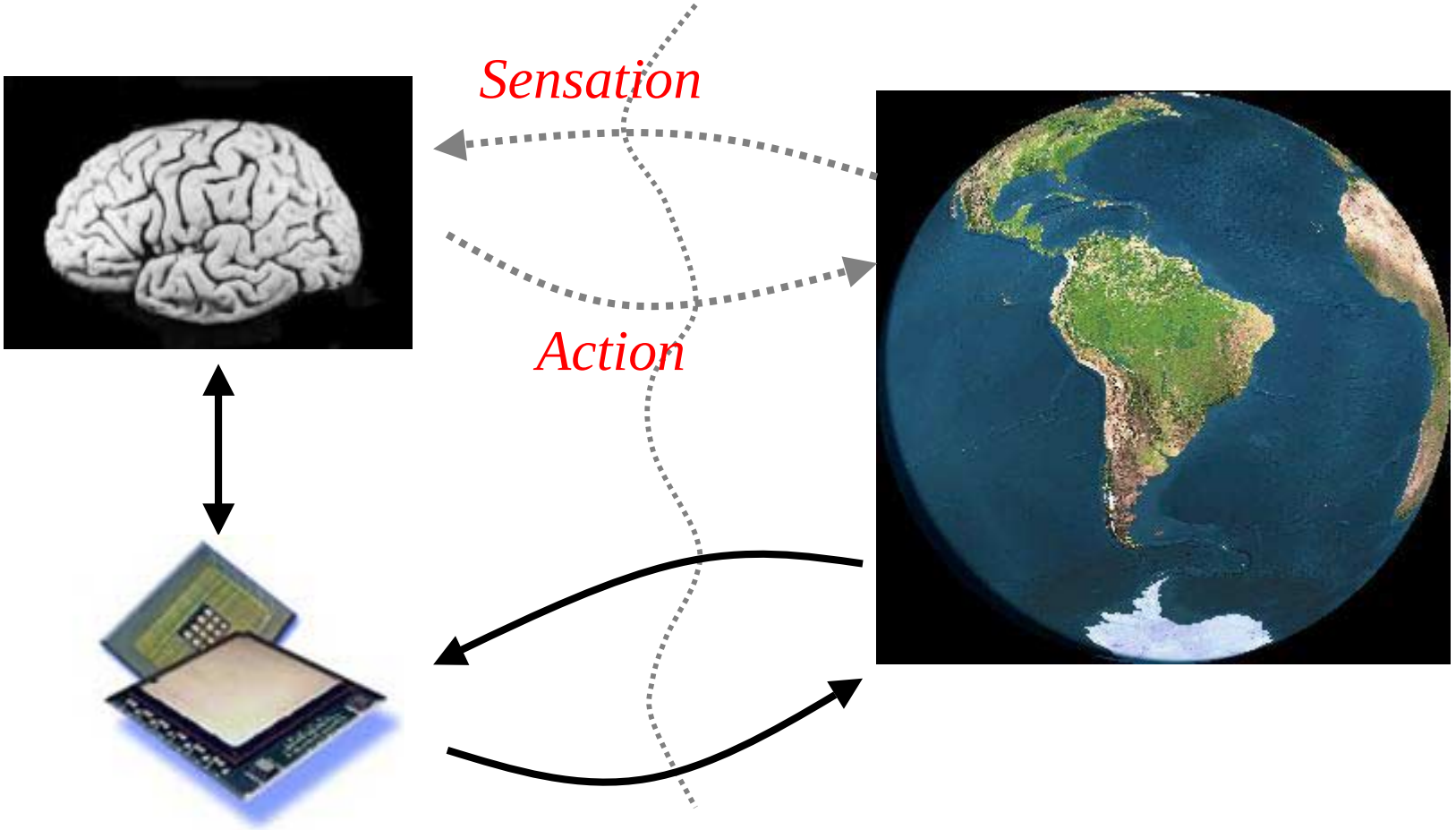
Curt Siodmak, 1942

NEURAL PROSTHETICS

Sensation

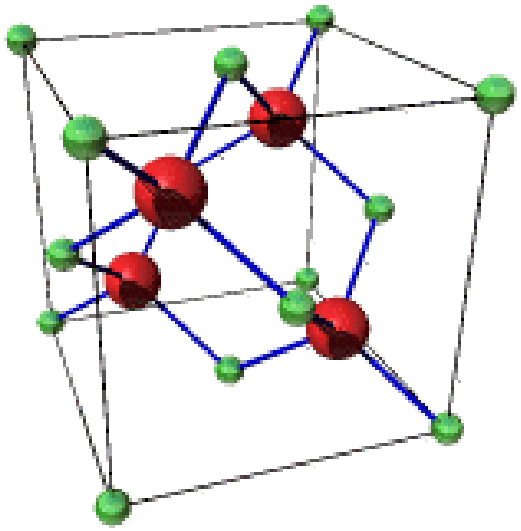
Action

NEURAL PROSTHETICS



Why is studying the brain difficult?

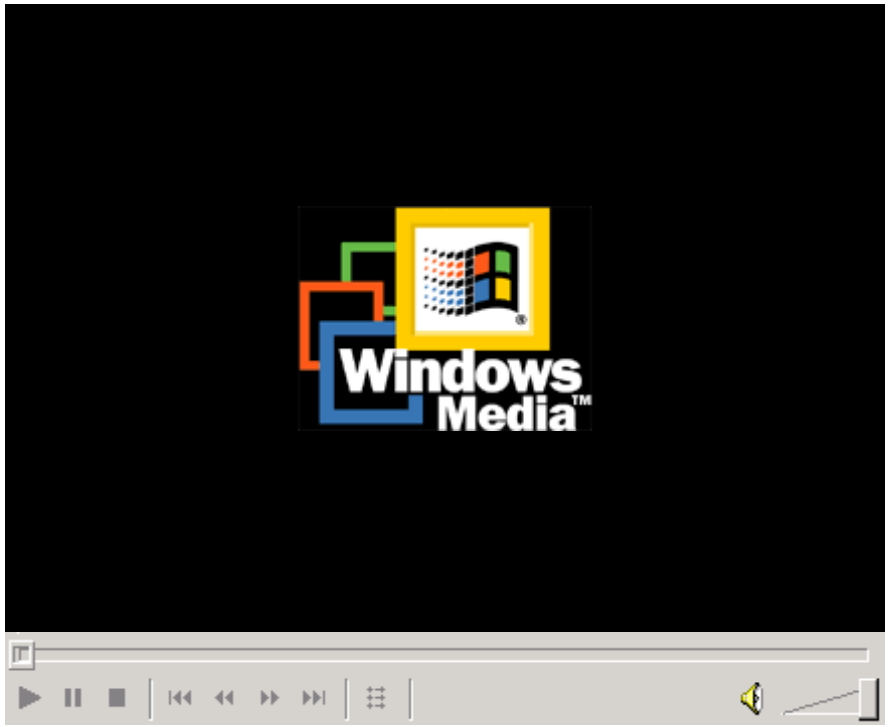
3D Topology in Physics



gallium arsenide

interactions between constituents
of **physical** systems take place in
3-D topology

3D Topology in Biology

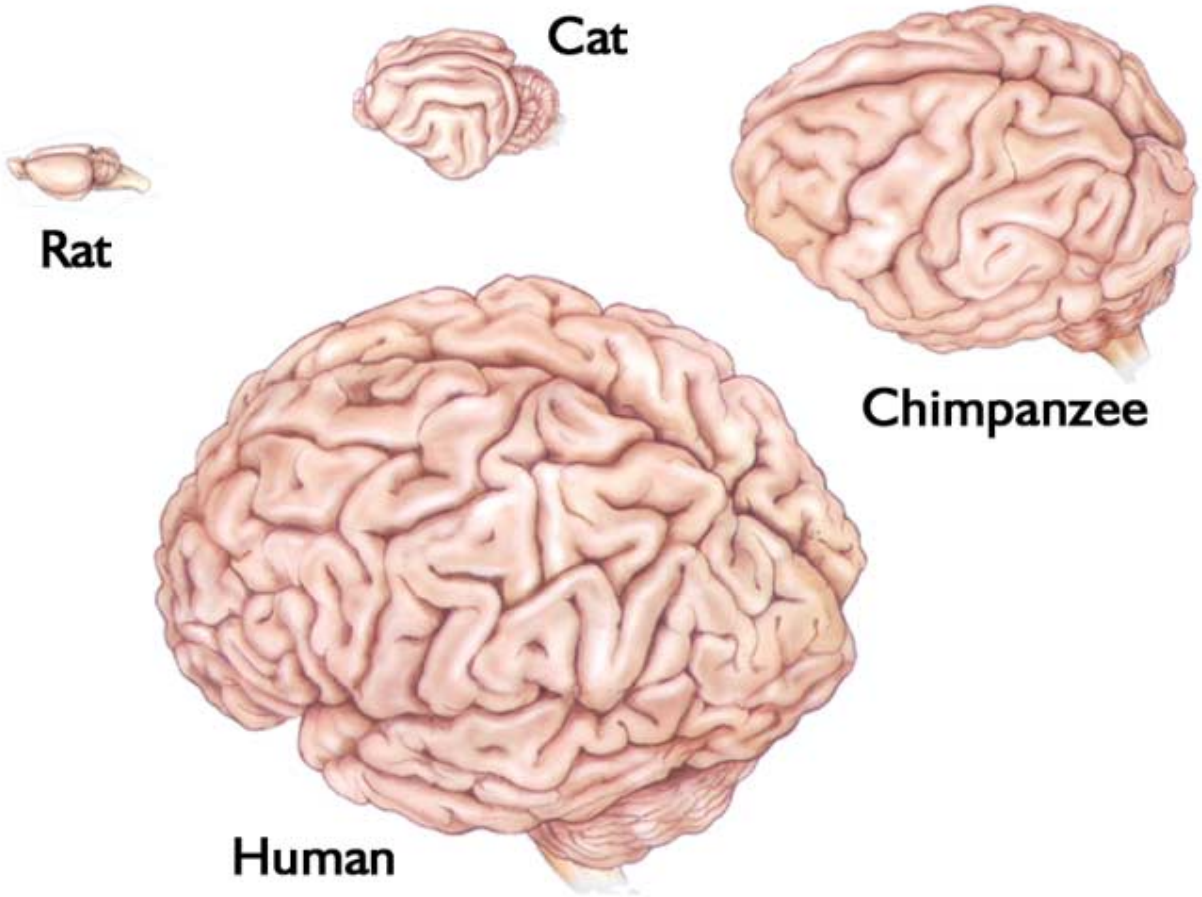


four stages of folding of poly-leucine into an alpha-helix and insertion into a membrane

- interactions take place in 3-D topology
- simulation on supercomputer takes months

*n*D Topology of Cortex

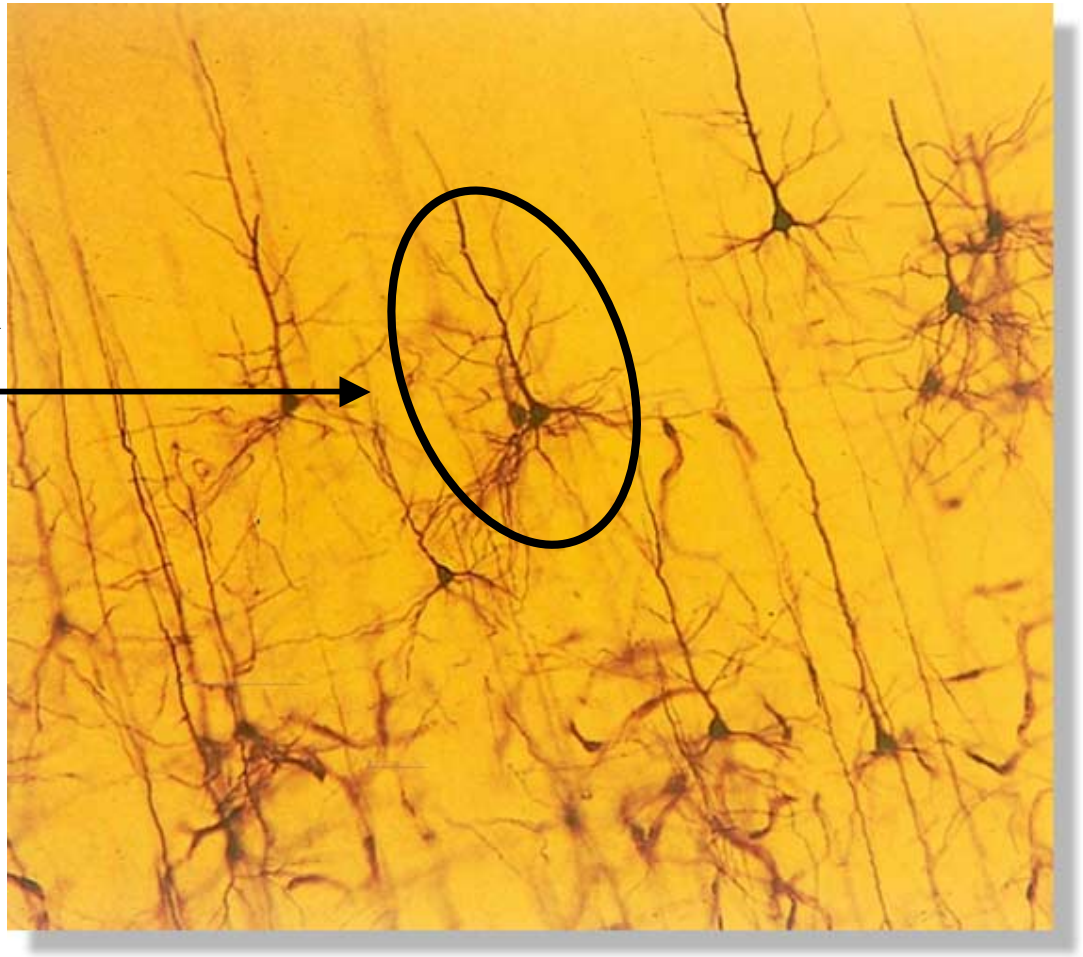
EXPLOSION OF CORTEX



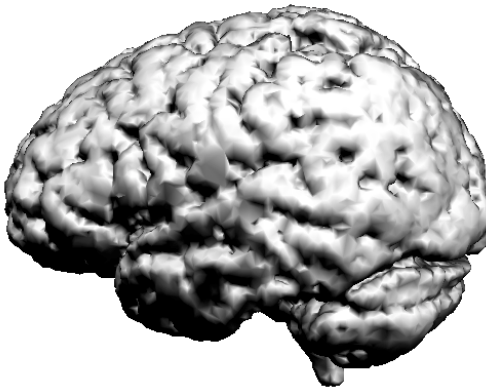
VISUALIZING THE PLAYERS

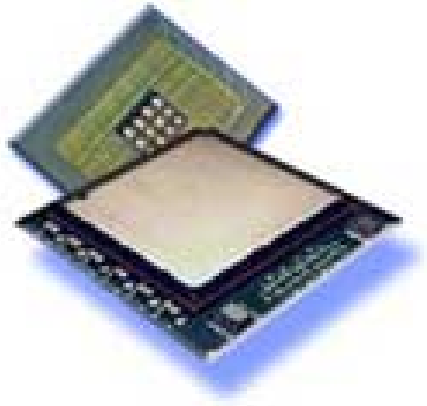
Single cells of
the nervous system

NEURON



BRAIN VERSUS COMPUTER



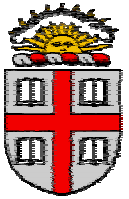


Computational Elements

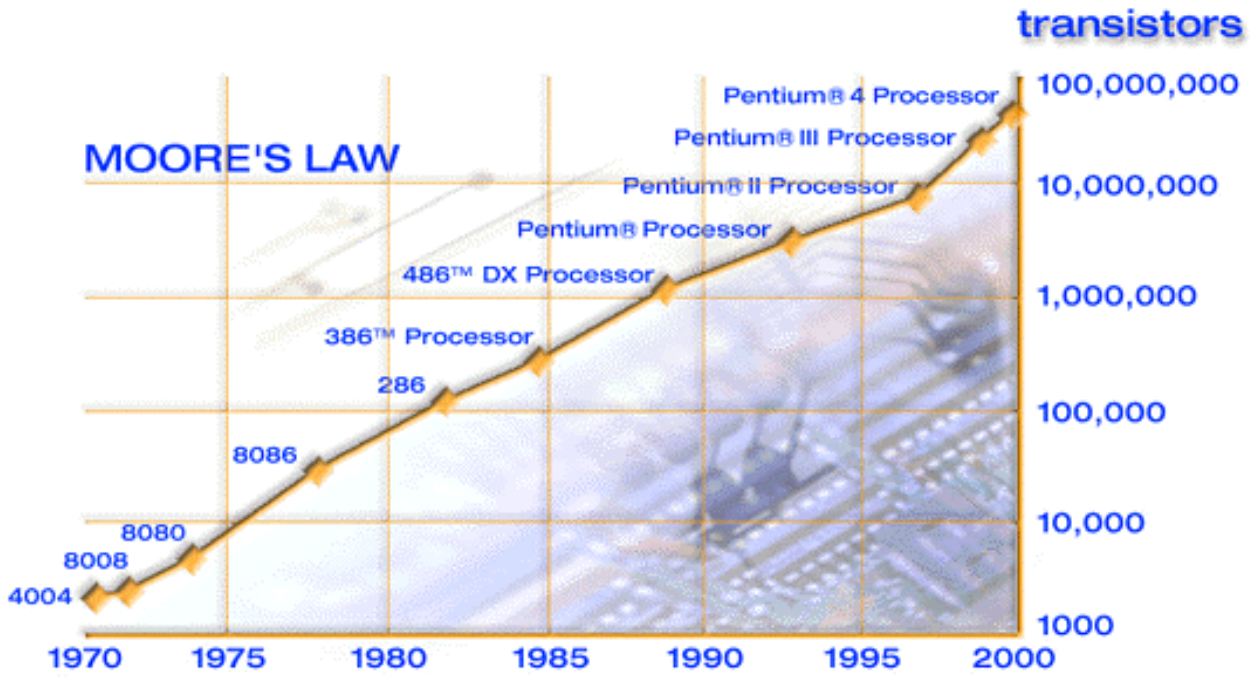
100,000,000,000	100,000,000
Neurons	Transistors

Speed (operations/second/element)

30-300	$1.5 * 10^9$

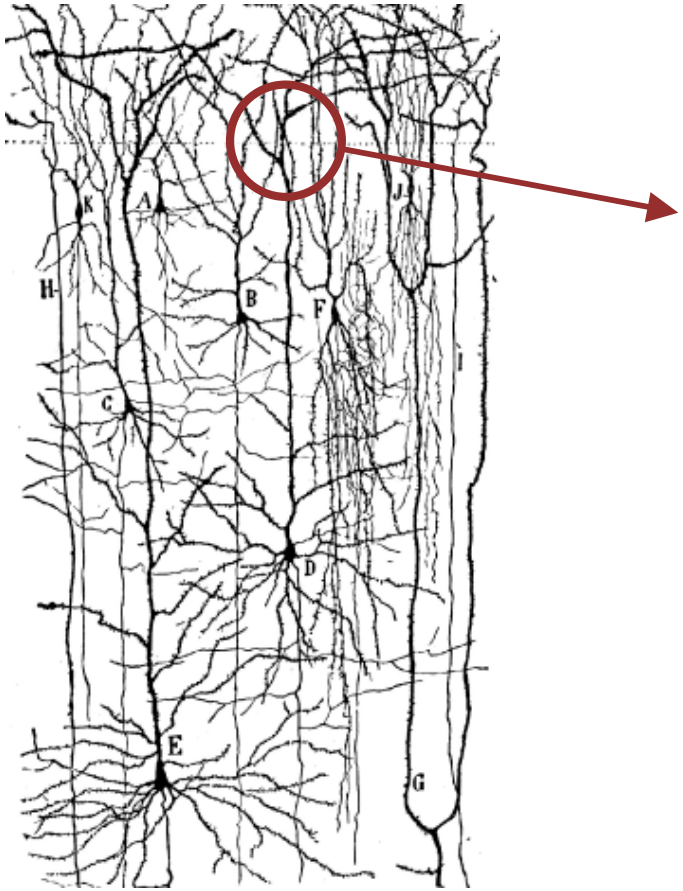


MOORE'S LAW

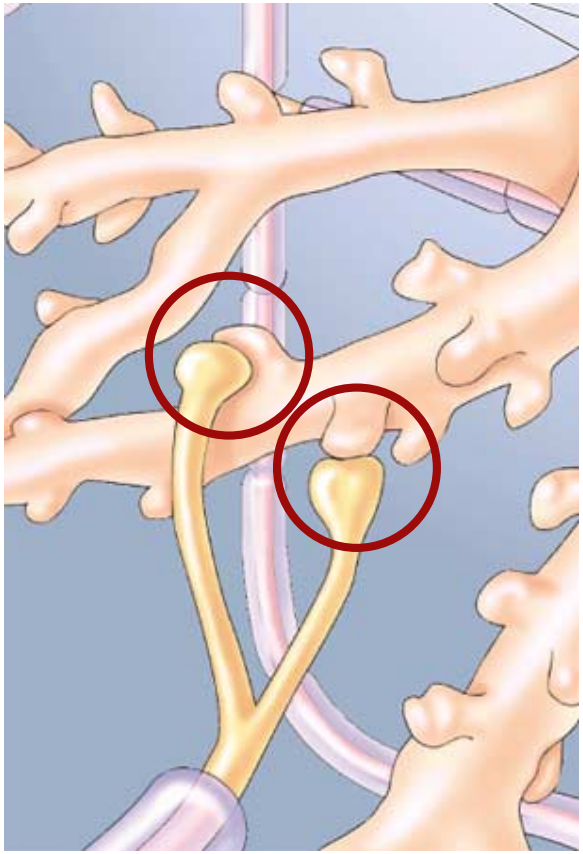


Intel

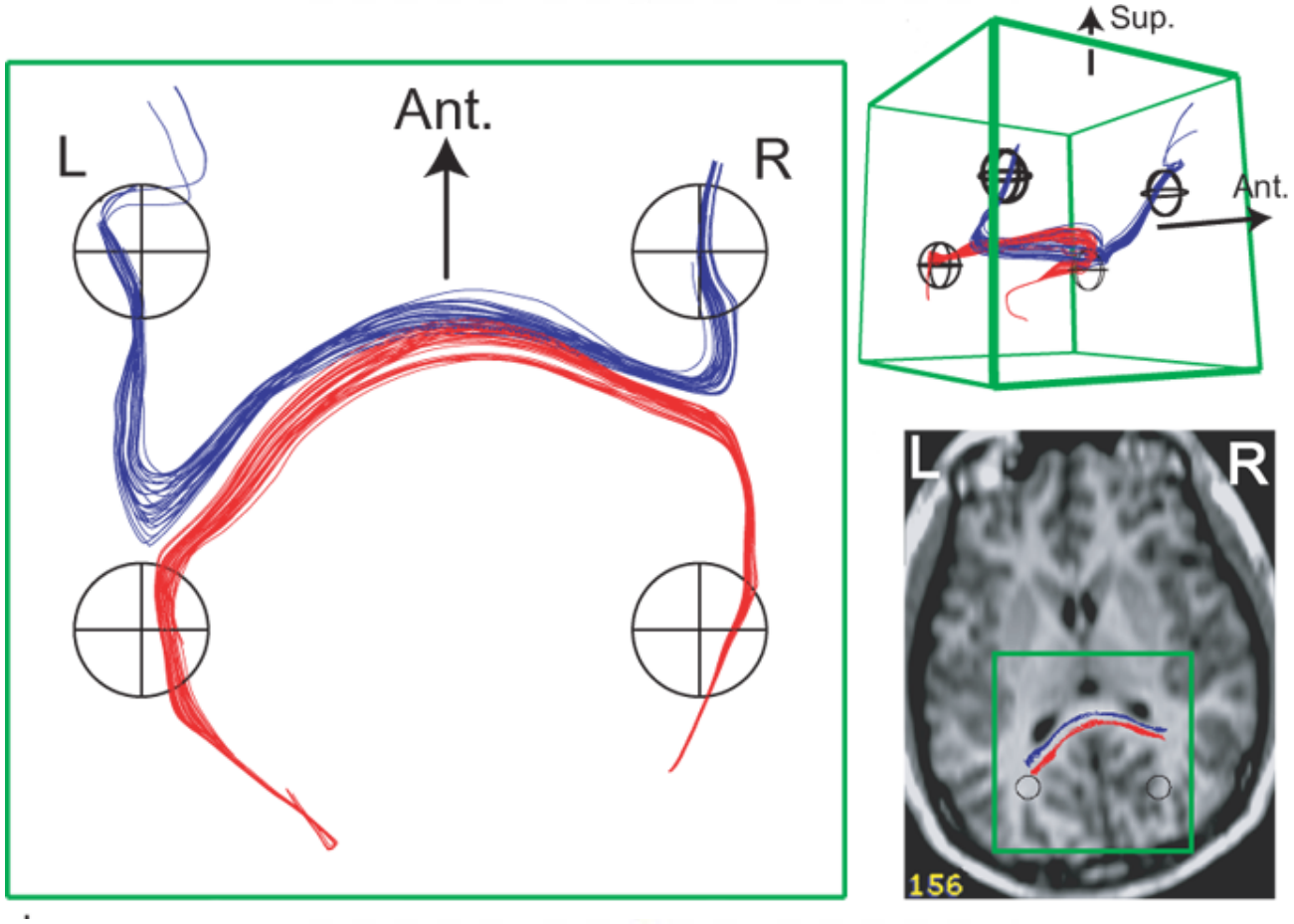
MASSIVE CONNECTIVITY



SYNAPSES



LONG DISTANCE CALLS



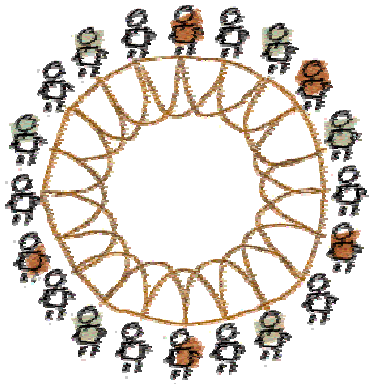
Conturo et al., 1999

IF EACH NEURON WERE A PERSON…

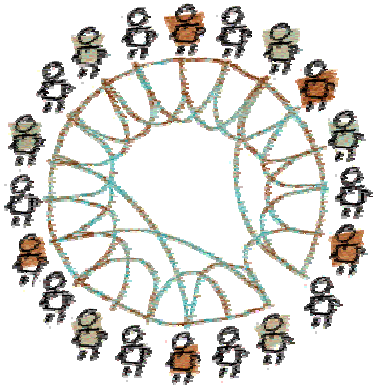
Cortex would be:

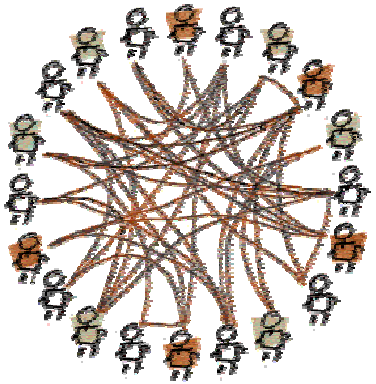
- a world of about 10^{11} people,
- each person communicating through a direct high-speed private line with about 10^{3} friends,
- about half of one's friends living in the same city,
- but many living in other continents …

DEGREES OF SYNAPTIC SEPARATION



1D graph





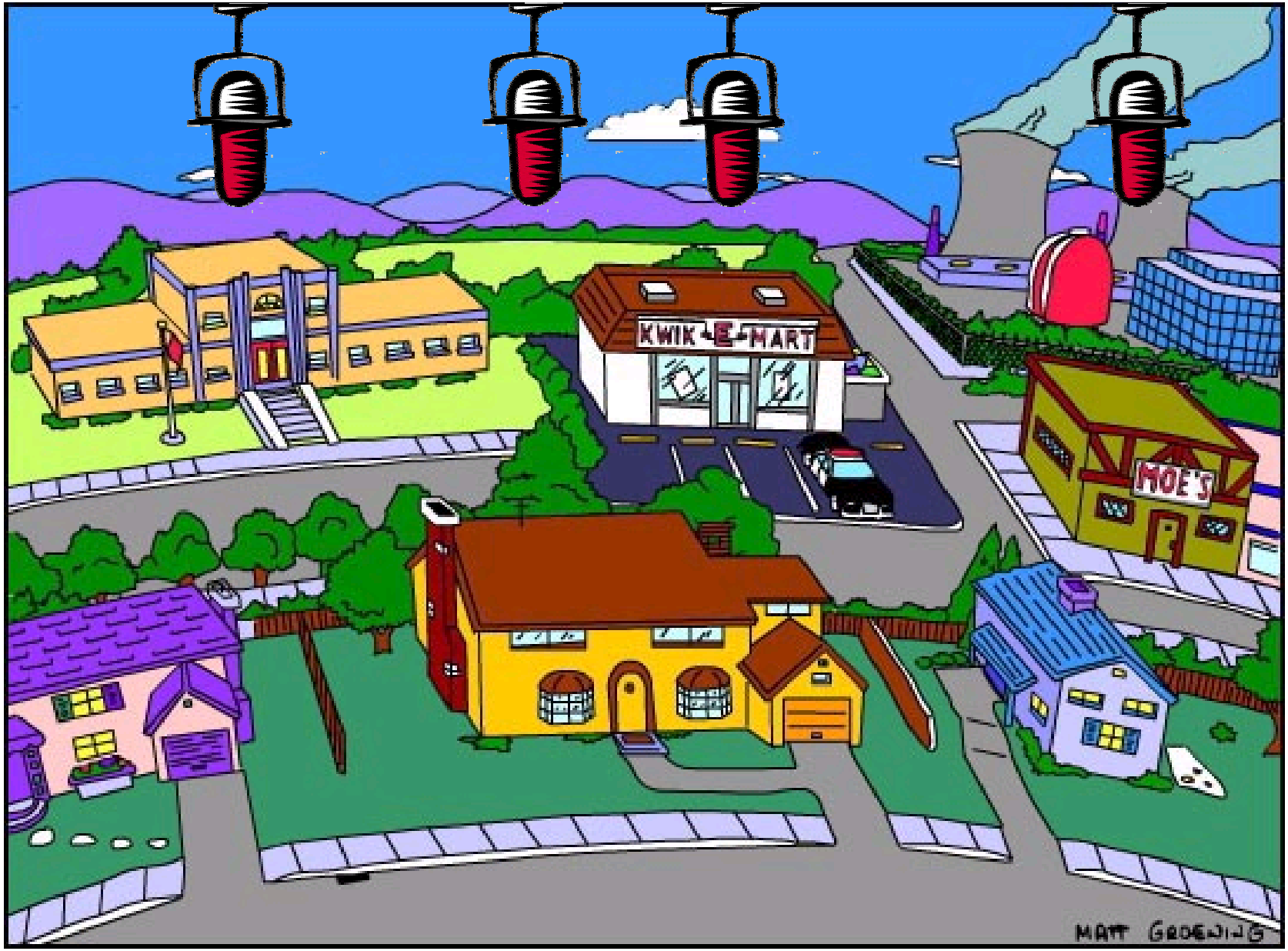
random graph

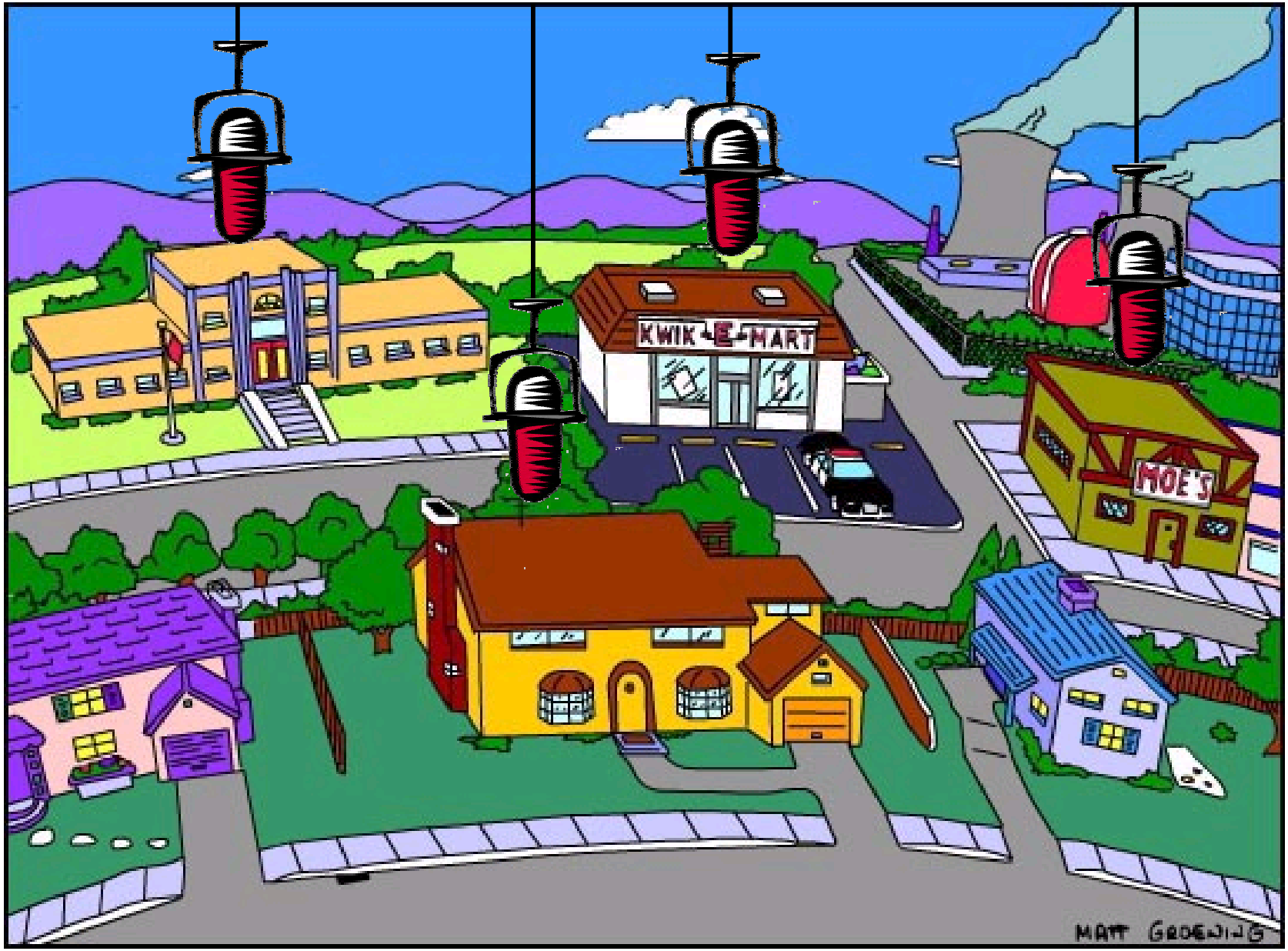
"small-world" graph

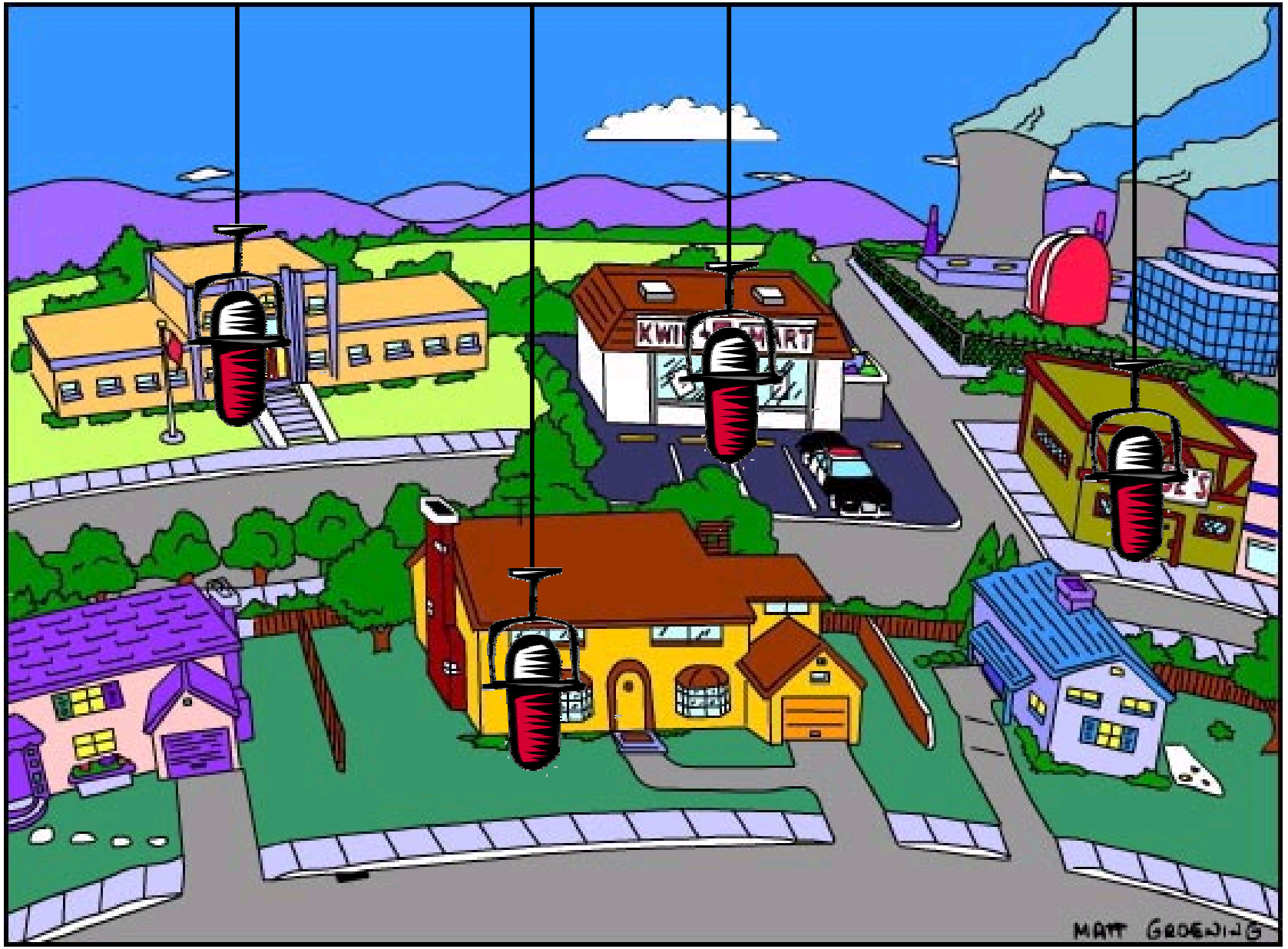
(*Duncan Watts, Steven Strogatz*)

Drawings: James Yang

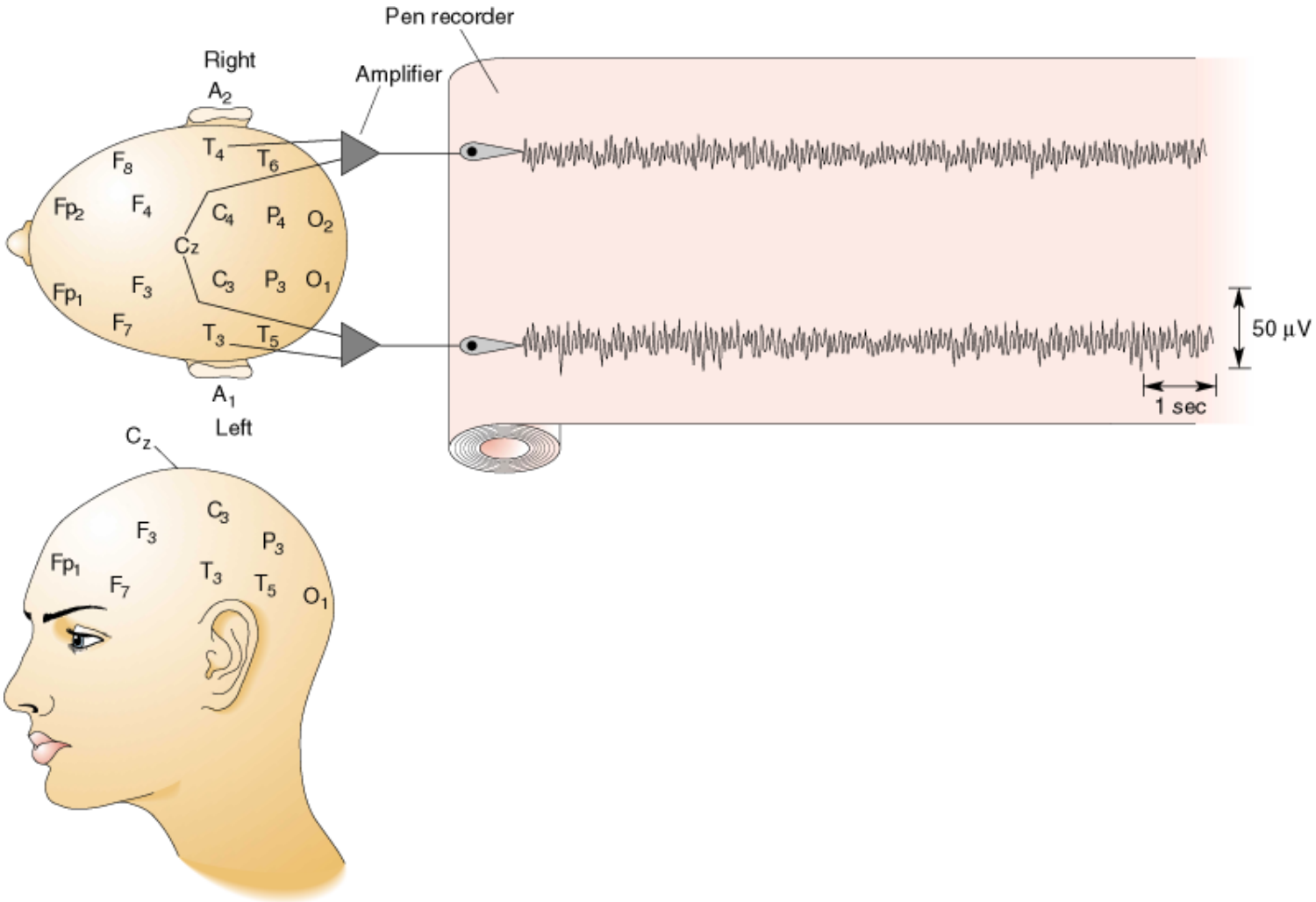
How do you study the brain?


KWIK E MART
MOE'S
MATT GROENING

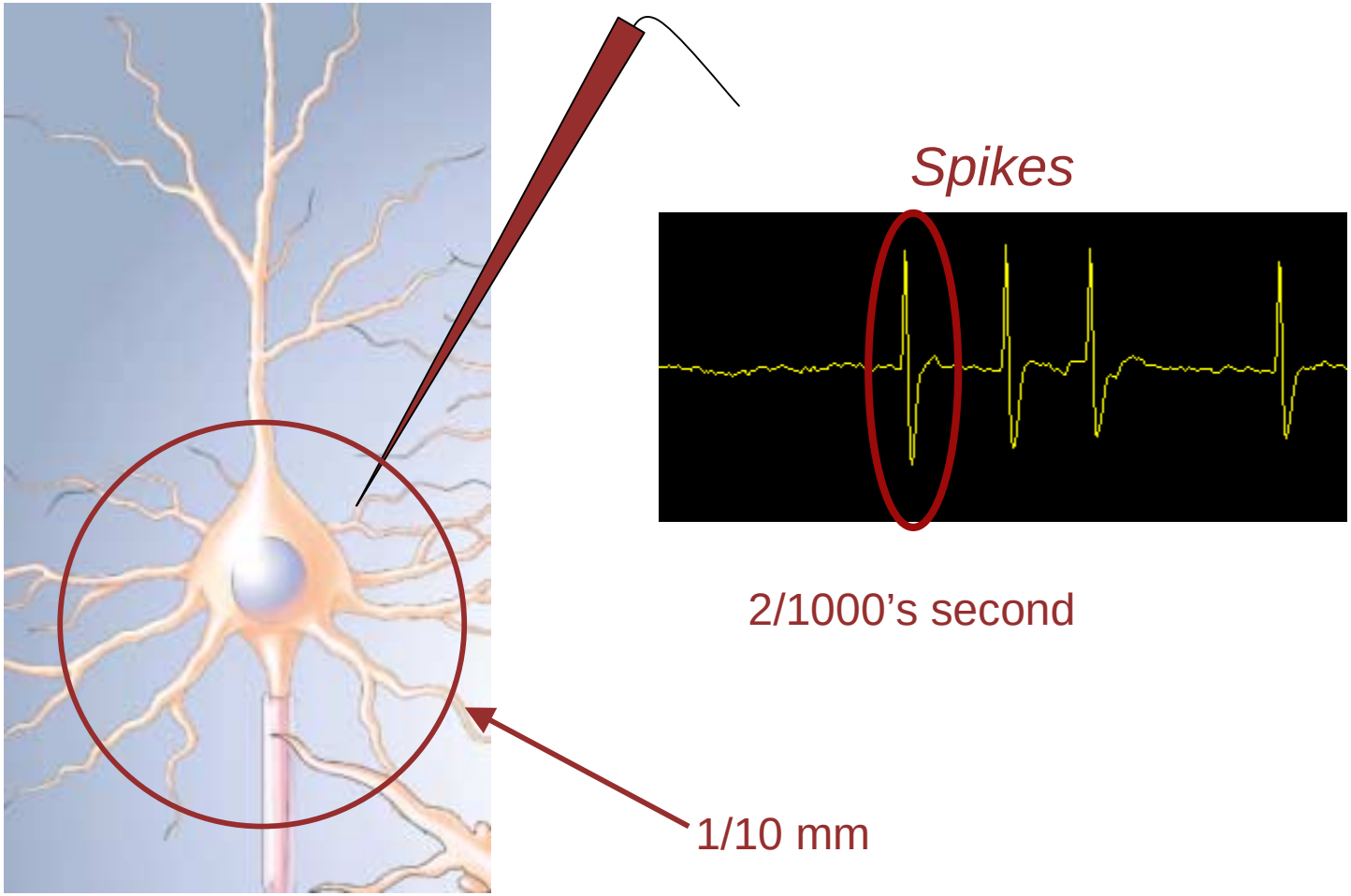

KWIK-E-MART
MOE'S
MATT GROENING


MATT GROENING

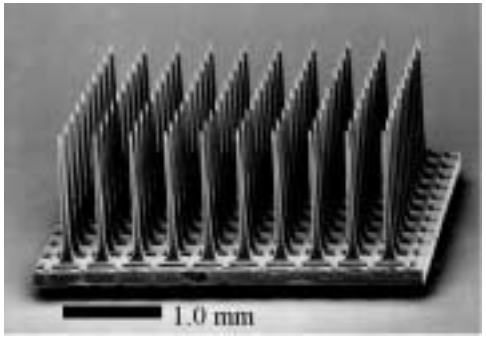
THE EEG

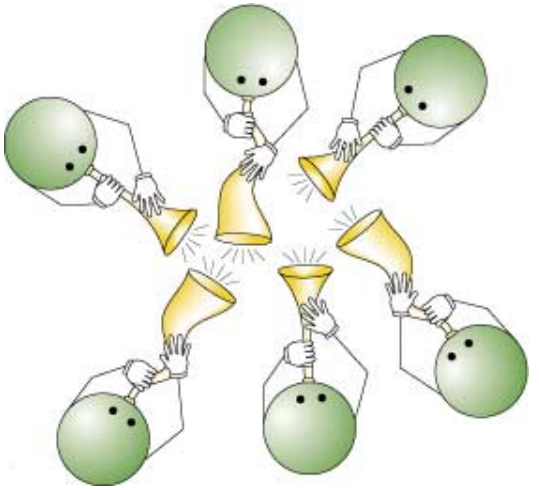

Pen recorder
Amplifier
Right
A_2
F_8
T_4
T_6
Fp_2
F_4
C_4
P_4
O_2
Cz
C_3
P_3
O_1
Fp_1
F_3
F_7
T_3
T_5
A_1
Left
50 µV
1 sec
Cz
C_3
F_3
P_3
Fp_1
T_3
T_5
O_1
F_7

SINGLE UNIT ACTIVITY

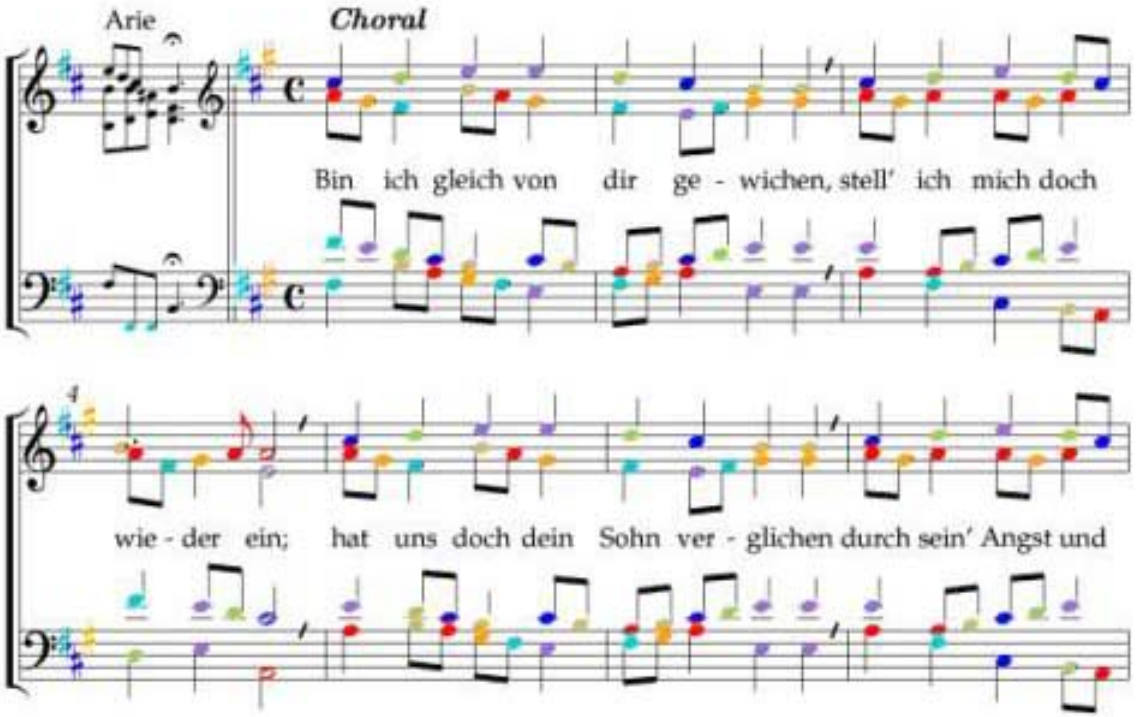


CELL ENSEMBLES

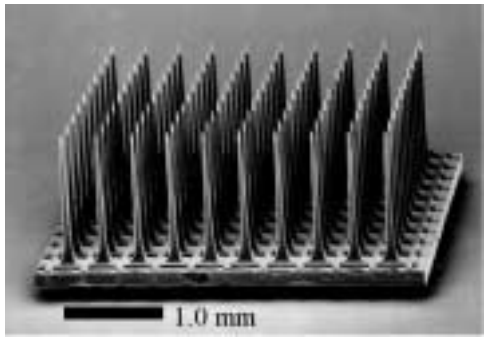


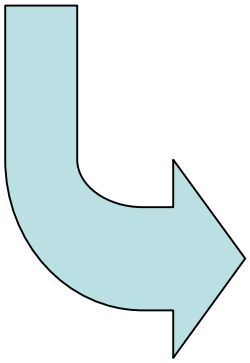


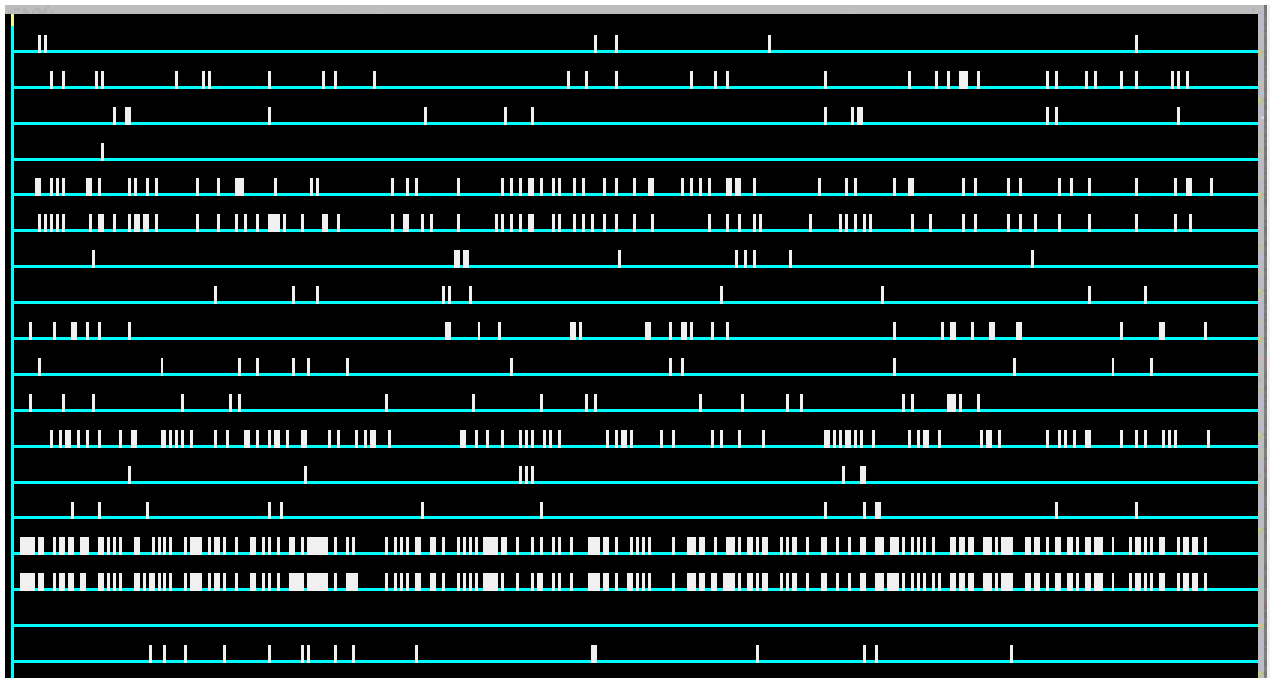
PATTERNS IN MUSIC



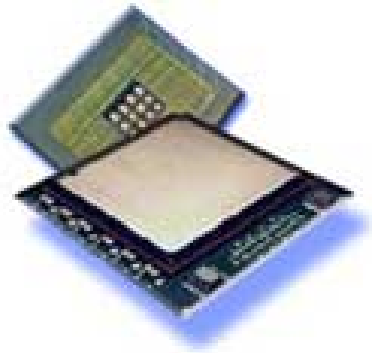
PATTERNS IN NEURAL ACTIVITY



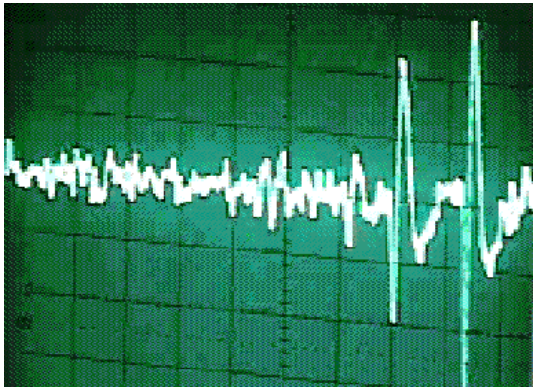




LANGUAGE OF THE BRAIN



Language of the brain.



Interpretation

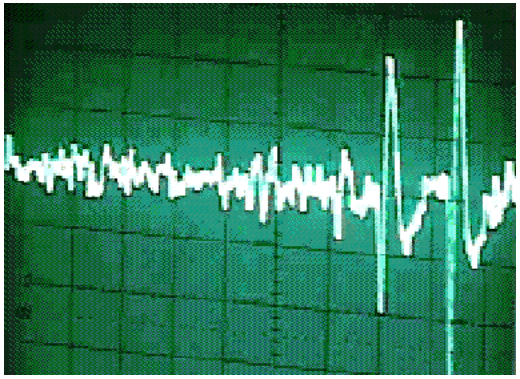
“Translation”

Language of the computer.

AMBIGUOUS SIGNALS

INFERENCE

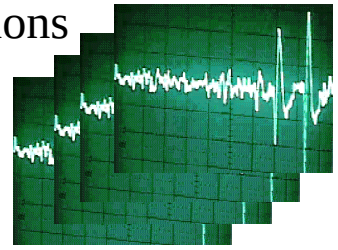
Ambiguous measurements



"Prior" knowledge about how brains work.

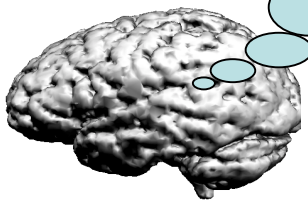
"Prior" knowledge about the environment

History of measurements and interpretations



Inference

?

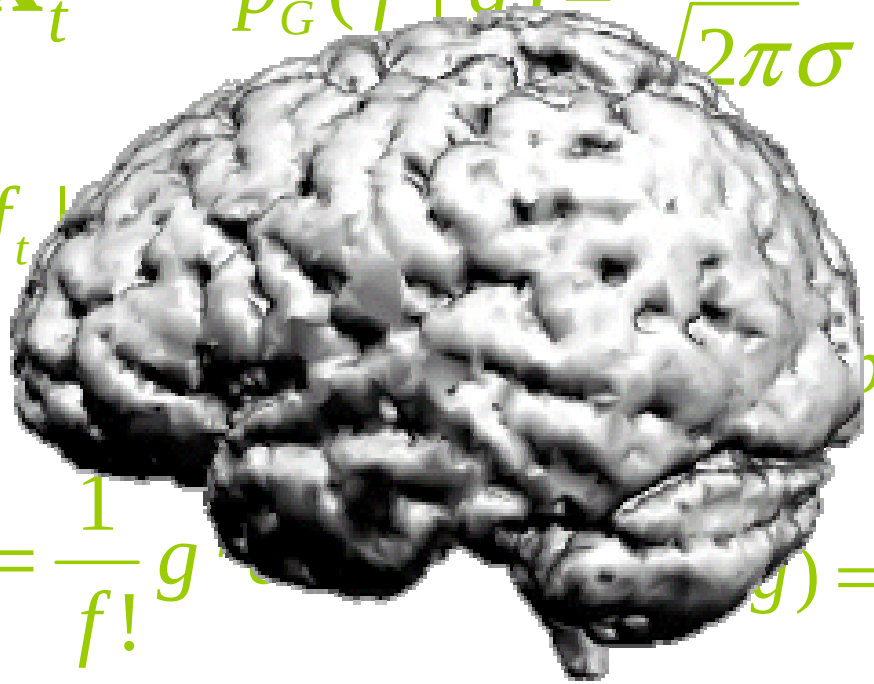


THE MATHEMATICS OF MIND

$$\mathbf{y}_t = A\mathbf{x}_t$$

$$p_G(f \mid g) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(-\frac{(f-g)^2}{2\sigma^2}\right)$$

$$-\Sigma_t \log(p(f_t \mid$$



$$p(f_v \mid g_v)p(g_v|\mathbf{g})$$

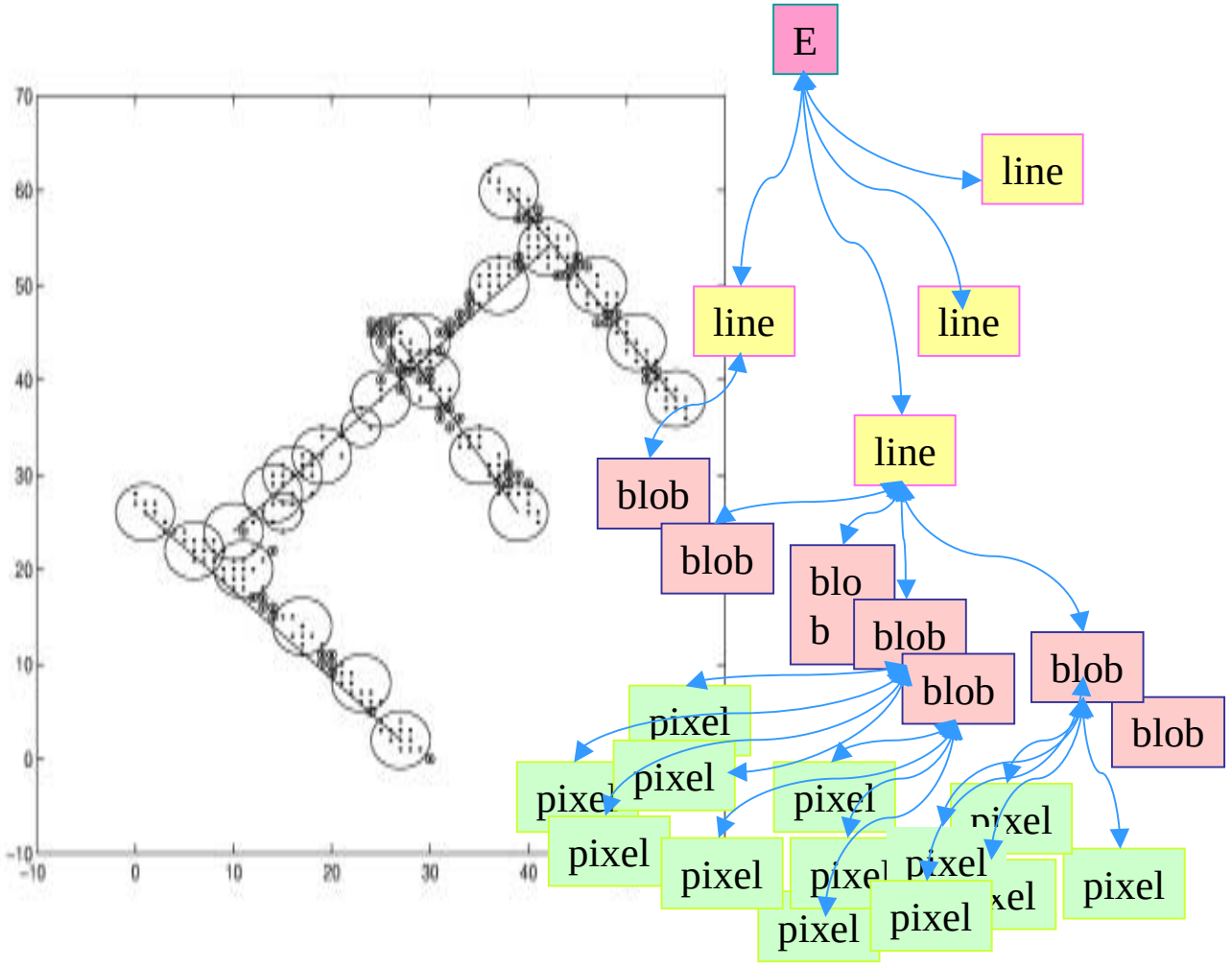
$$p_P(f \mid g) = \frac{1}{f!} g$$

$$g) = \frac{2\sigma^3}{\pi(\sigma^2 + \Delta g^2)^2}$$

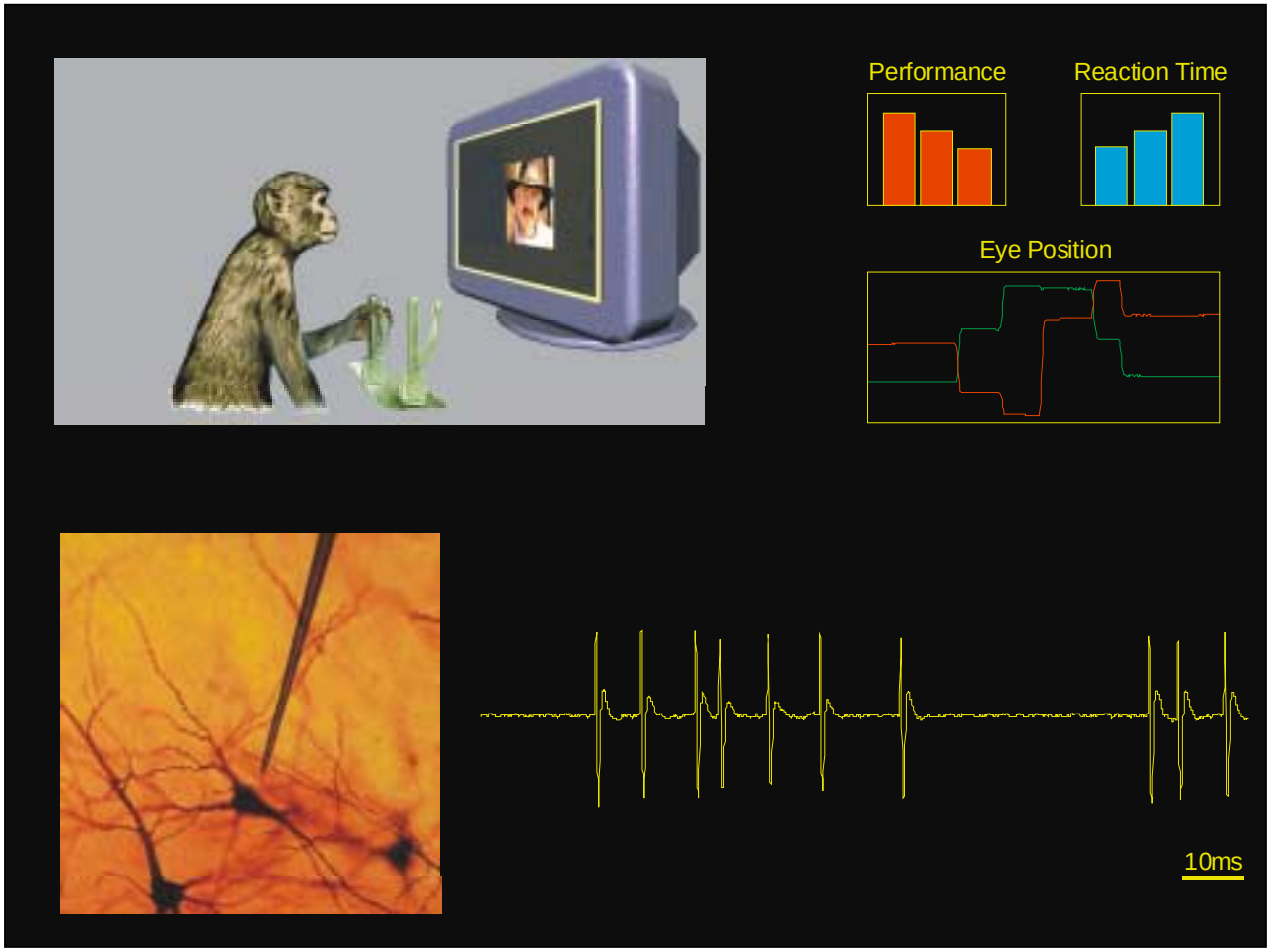
$$p(\mathbf{g}|\mathbf{f}) = \Pi_{\mathbf{v}} (\kappa p(f_v \mid g_v) \Pi_{i=1}^{\eta} p(g_v \mid g_{\mathbf{v}_i}))$$

Brain Science Today

ALGORITHMS FOR VISION



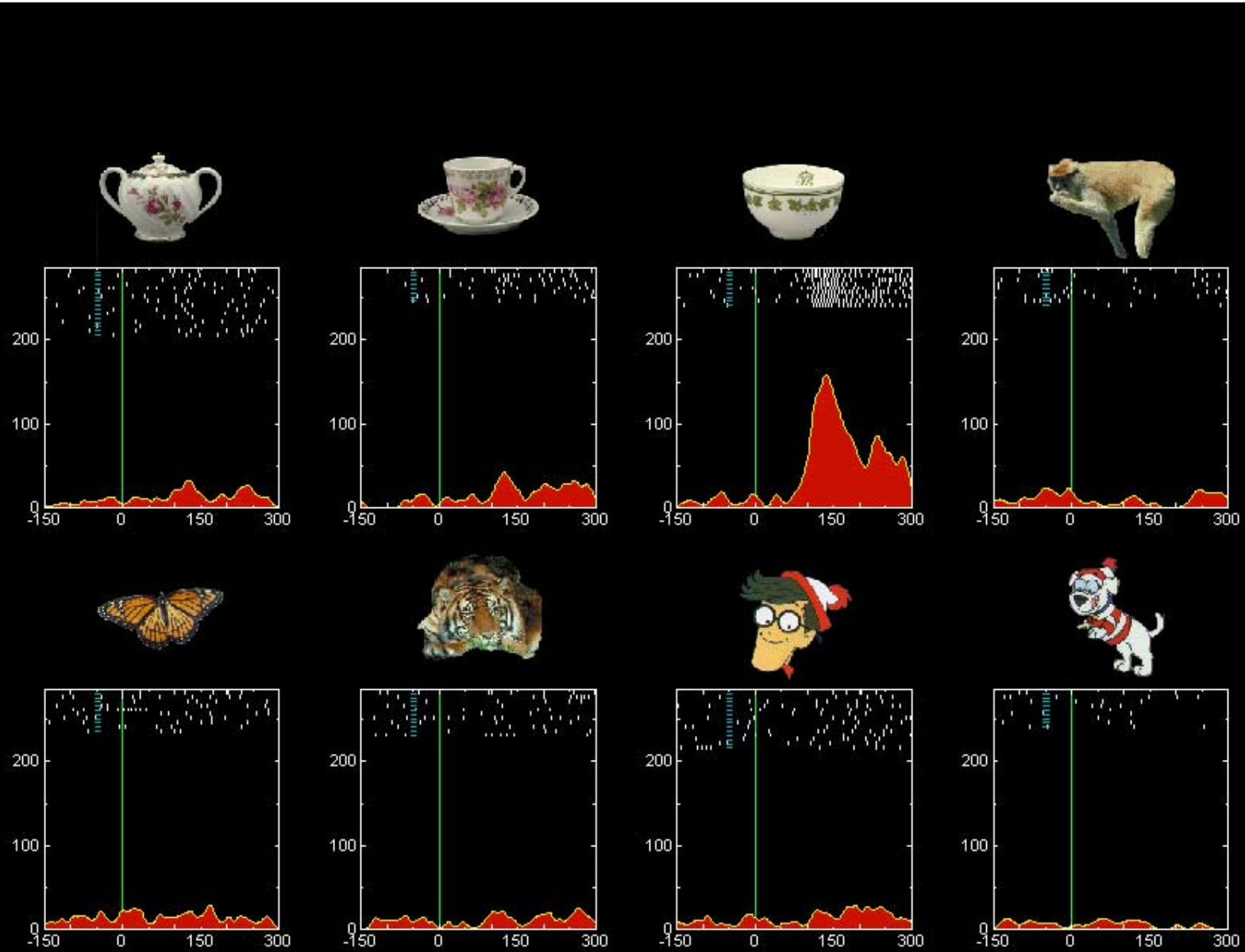
DECODING NEURAL MESSAGES



BEHAVIOR

NEURAL SIGNAL

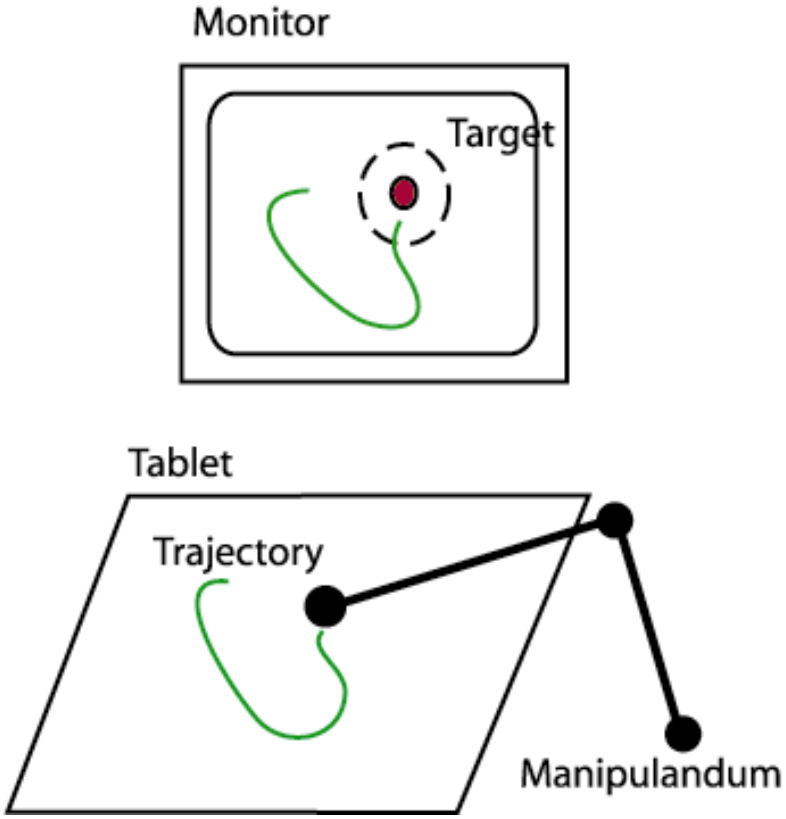
Neural Representations


200
100
0
-150
0
150
300

Active Visual Processing

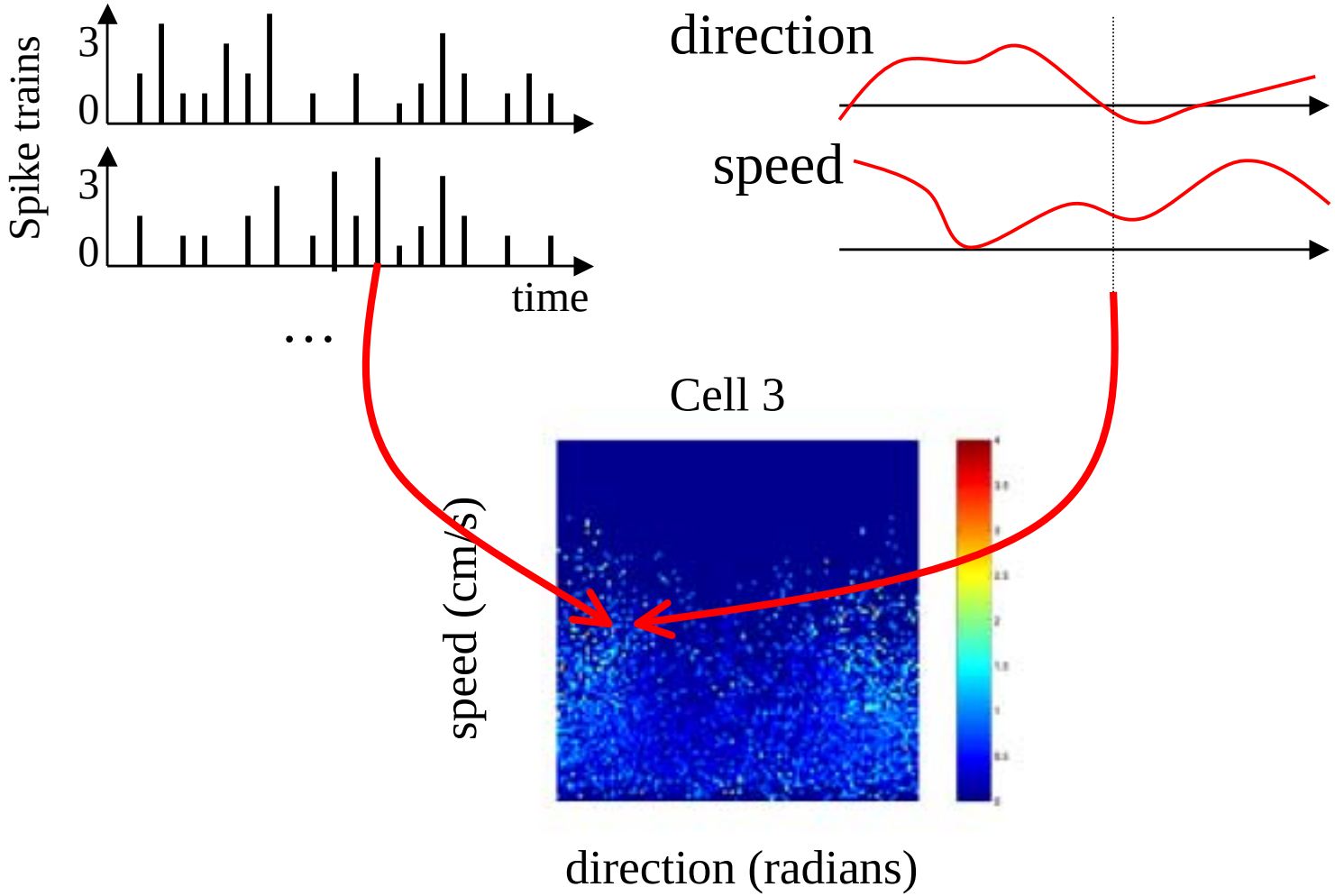
Neurons and Behavior

MODELING NEURAL FUNCTION

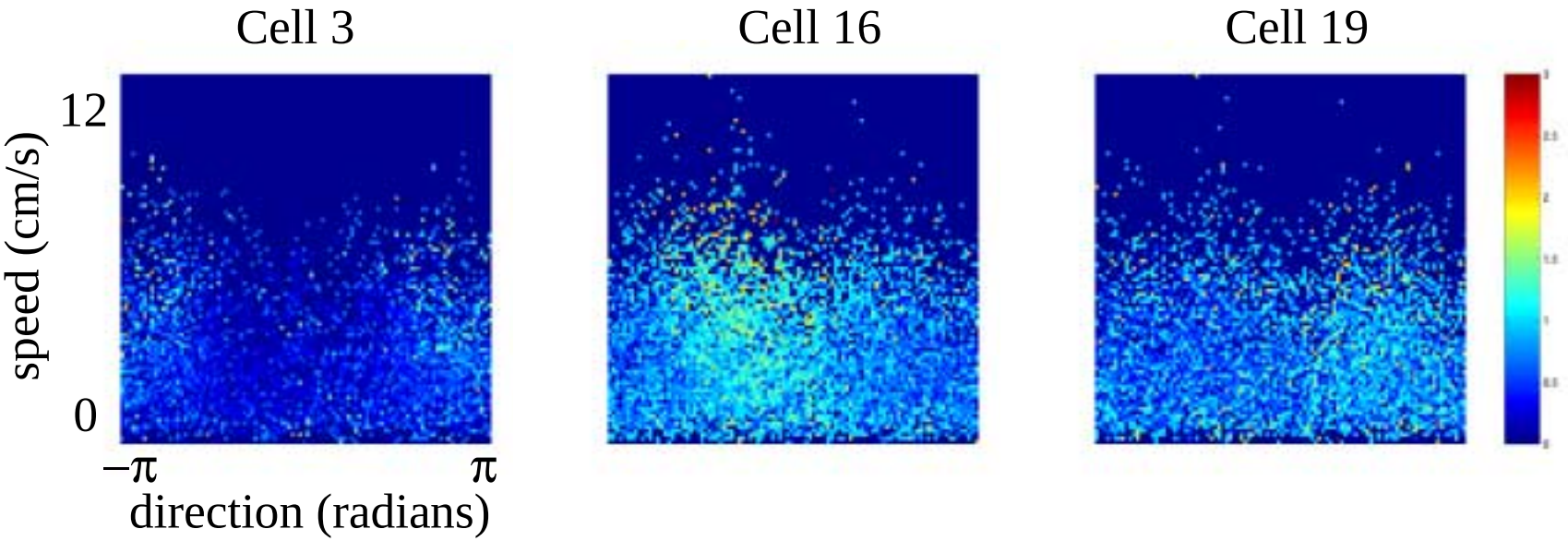


Simultaneously record hand position, velocity, and neural activity in motor cortex.

MODELING NEURAL FUNCTION

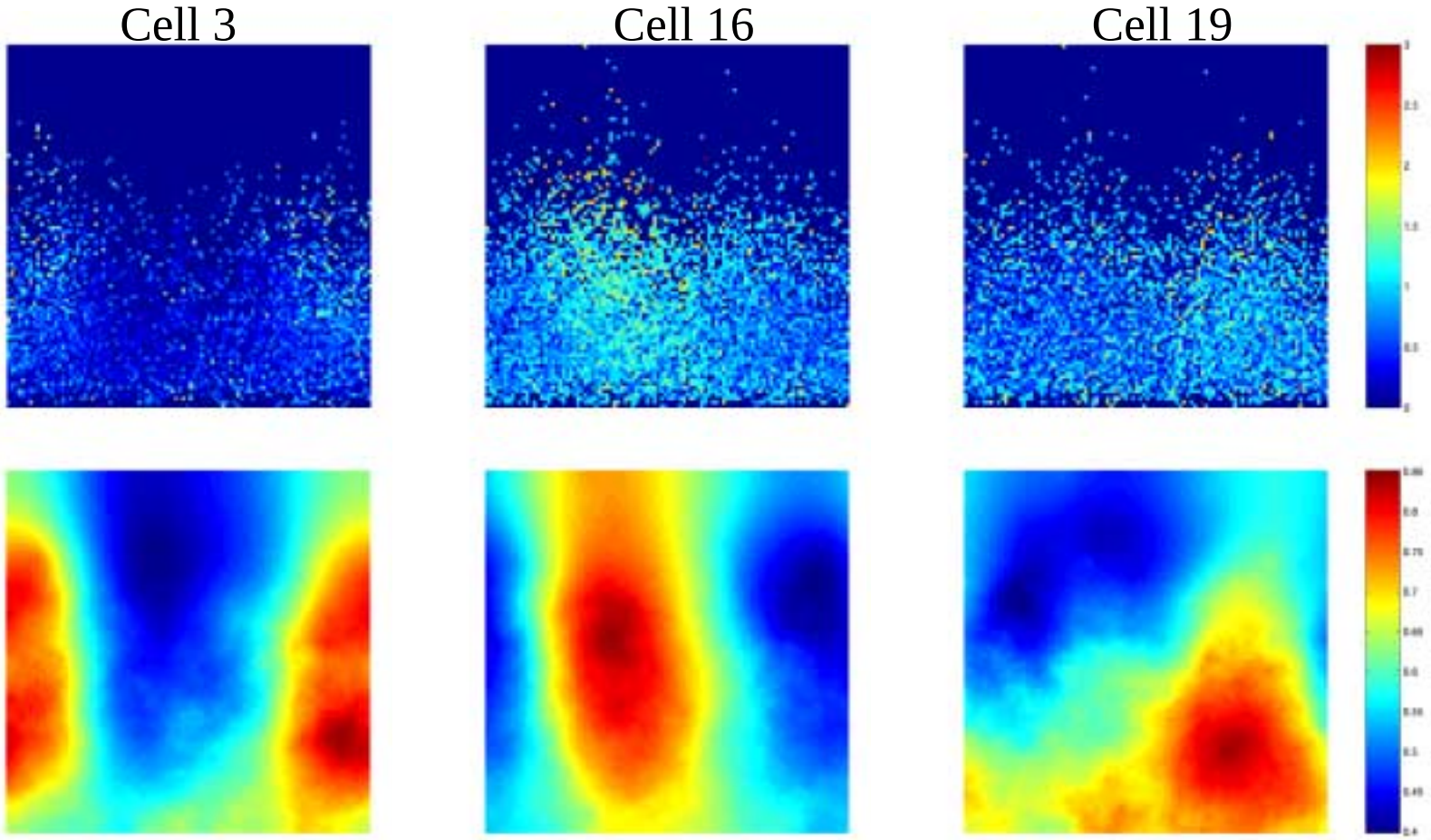


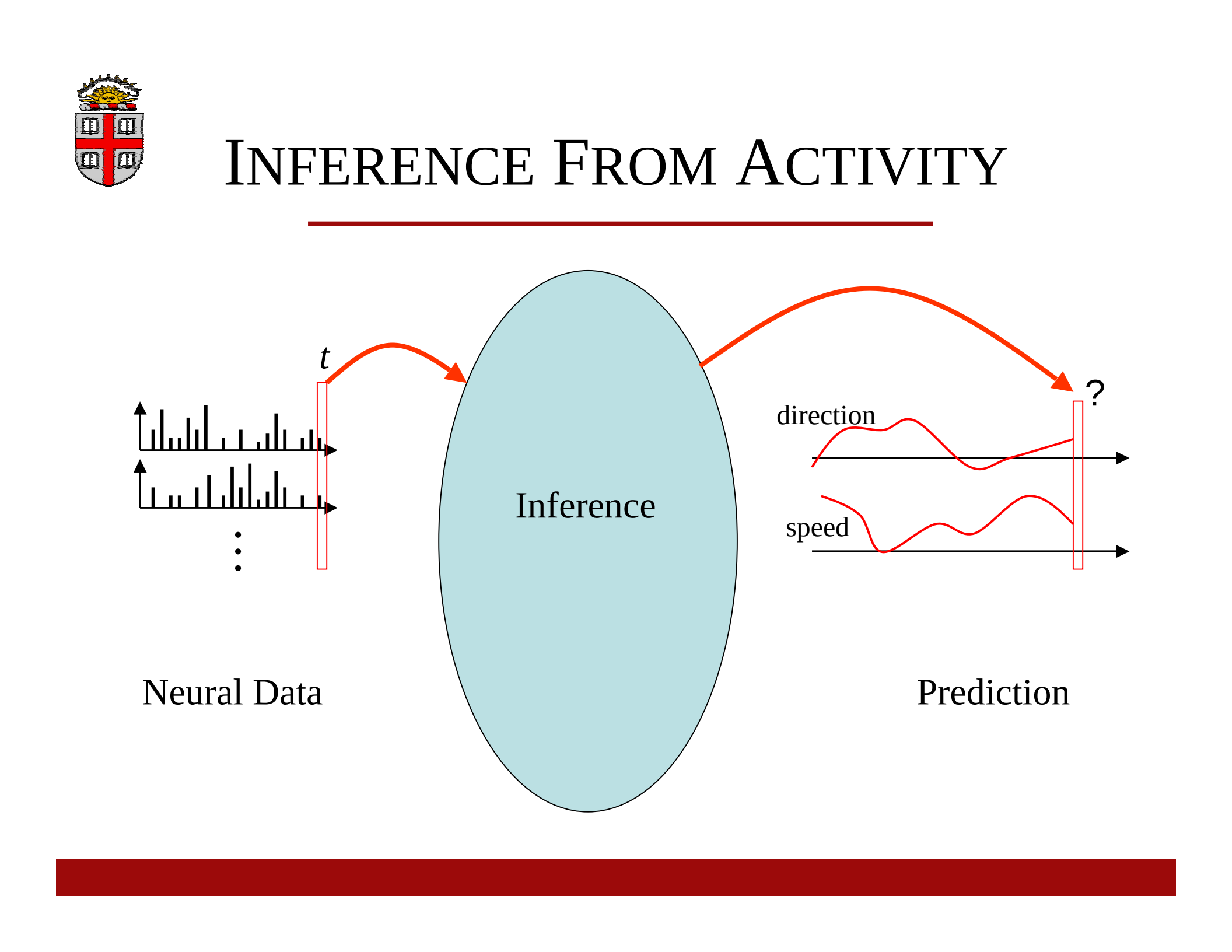
NEURAL ACTIVITY



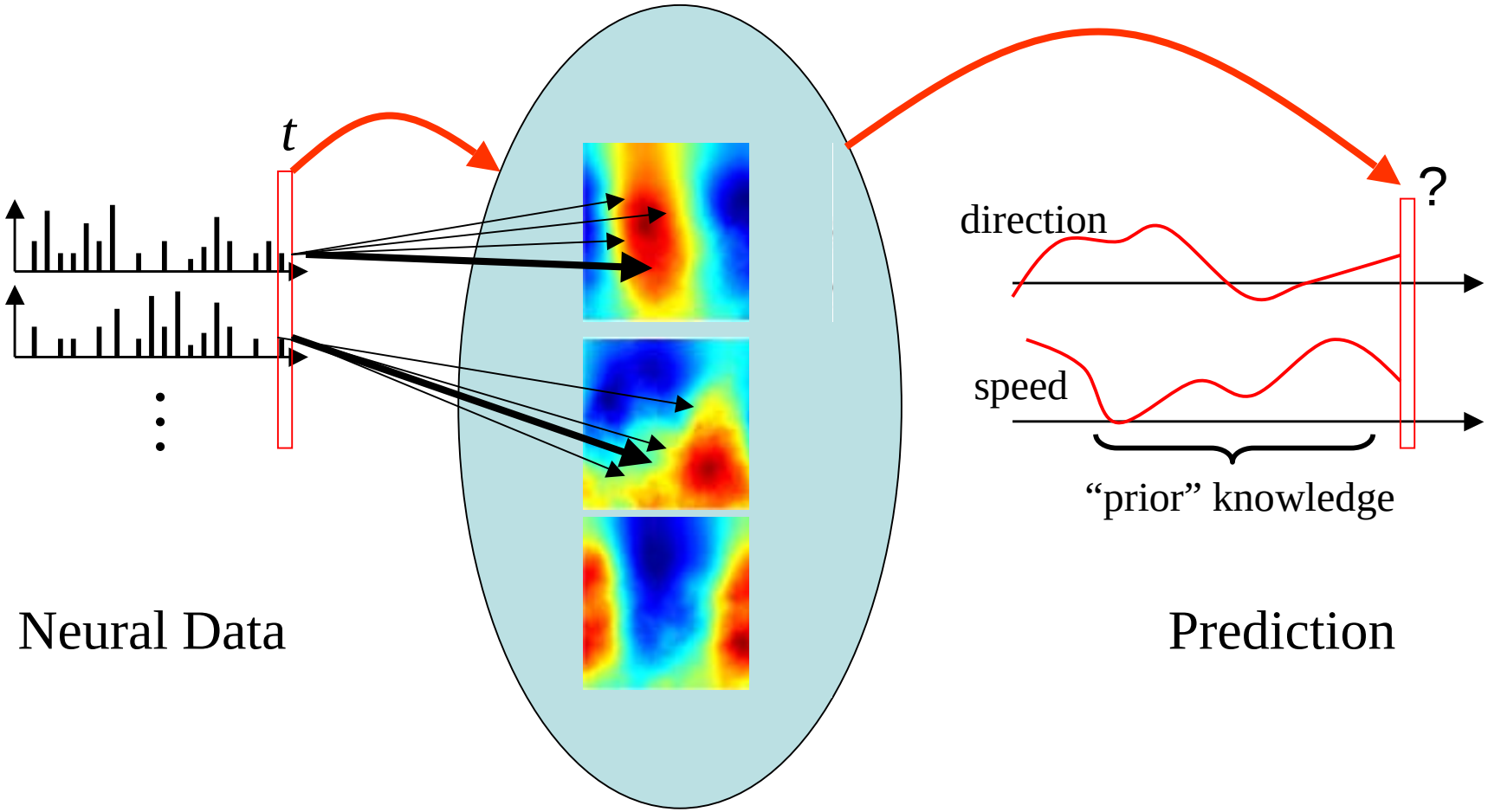
Is there some “true” underlying response function?

Modeling Neural Activity

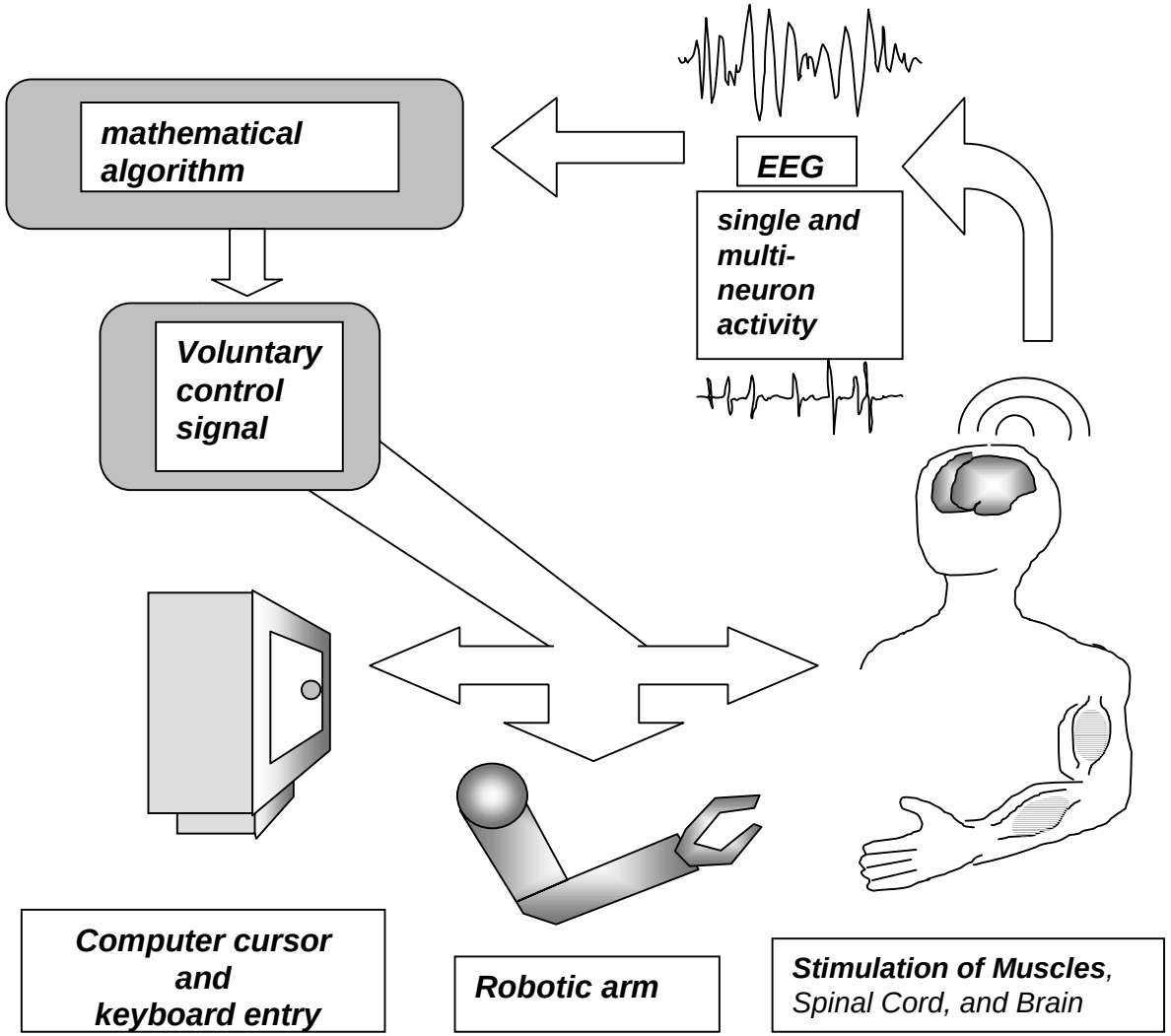



INFERENCE FROM ACTIVITY
t
Inference
?
direction
speed
Neural Data
Prediction

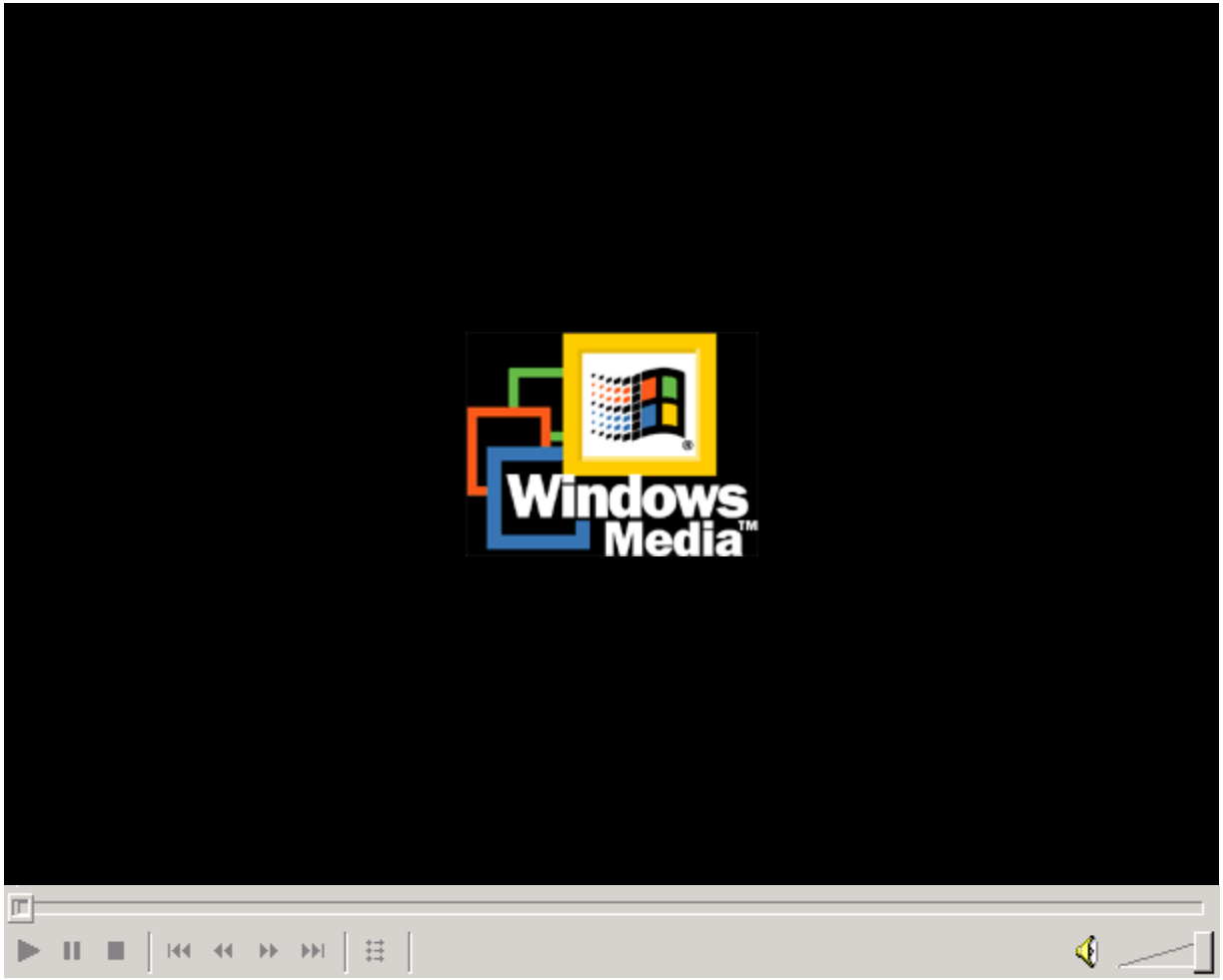
INFERENCE FROM ACTIVITY



A NEURAL PROSTHETIC

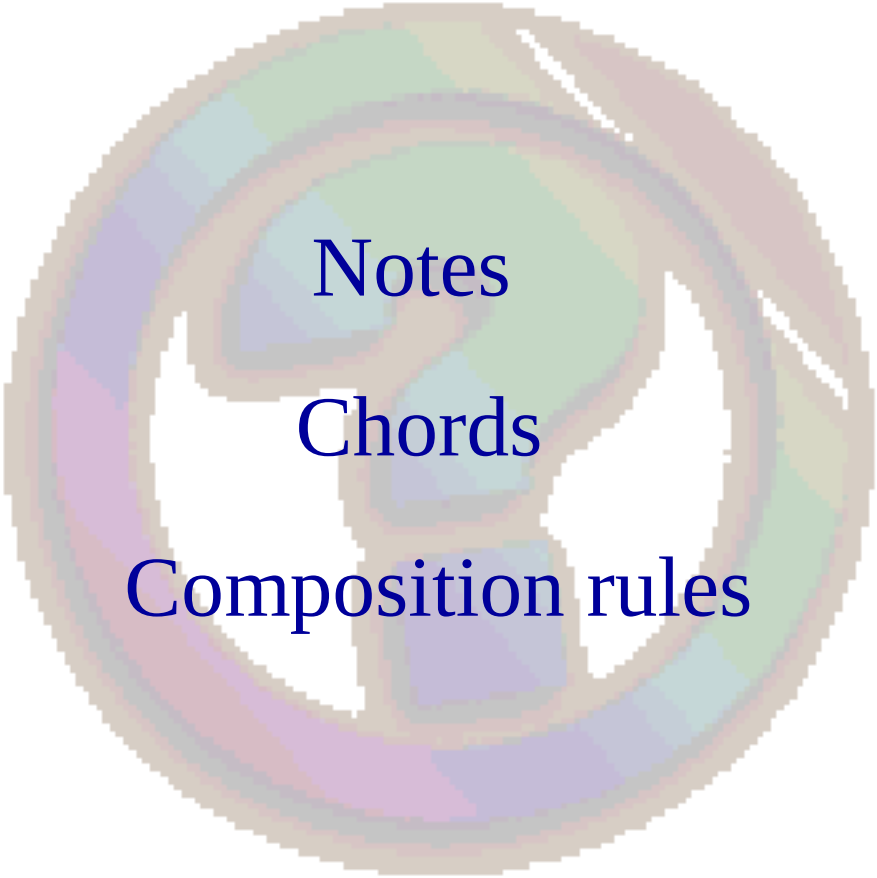


NEURAL-PROSTHETIC LIMBS



Our Goals

MUSIC OF THE BRAIN

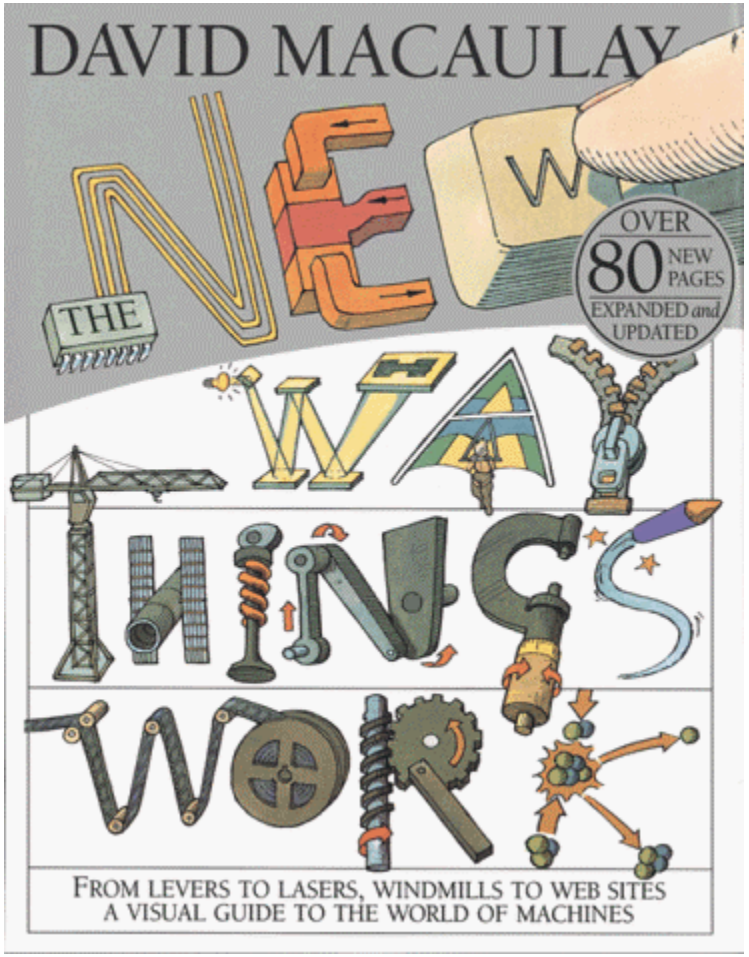


Notes

Chords

Composition rules

UNCOVERING THE MECHANISM



The Man Who Mistook His Computer for a Hand

- Hybrid, brain-computer, systems.
  - new physical pathways for interacting with the world
  - the computer learns about the brain while the brain is constantly changing
- Metaphor:
  - from “desktop” to “body part”.

Our Bodies Ourselves?

- Service robots under neural control.
- Sensation and action at a distance.
- Stimulating the brain.

Ethics, liminality, fear, and the “uncanny”.

Probotics/Jim Judkis

Honda robot

FUTURE

Music

Mechanism

Machine

THANKS

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